Name ____ AP Chemistry

Titration POGIL

A titration can be used to determine the concentration of an unknown solution using pH measurements and an acid-base indicator. There are two types of titrations: strong acid-strong base (relatively simple) and strong acid-weak base/strong base-weak acid (much more involved). This activity will help you learn how to identify each type of titration and how to calculate given points in the titration given the basic information. However, first we need to start with some basic vocabulary:

- titrant –solution in the buret with known concentration
- buret—calibrated volumetric instrument for dispensing a liquid
- indicator—substance which changes color in different [H_3O^+]
- titration curve—a plot of pH versus volume of acid (or base) added
- endpoint—point at which the indicator changes color
- equivalence point—point where moles H_3O^+ = moles OH^-

Titrations are performed by placing an acid or base of known concentration into a buret, called the titrant. This solution is then added to an acid or base of unknown concentration in flask that also contains an indicator. This acid-base indicator will change colors based on the pH or the amount of hydronium (H^+) ions. As the titrant is added to the flask, the pH is measured until the indicator changes color at the endpoint, signaling the reaction is complete. The volume of the titrant is then plotted against the pH in a titration curve to determine the equivalence point, or point at which the moles of hydronium and moles of hydroxide are equal. The equivalence point and endpoint should theoretically be the same but are often slightly off.

Most often titration curves are determined experimentally. However they can be produced through the calculation of pH at key points along the curve, given the initial concentrations of the acid and base. First you will look at how to construct a titration curve for a strong acid-strong base titration and then a strong base-weak acid titration.

Strong Acid-Strong Base Titration

Strong acid-strong base titrations are relatively simple to comprehend because both the acid and base completely dissociate. At any point during the titration, the pH can be calculated from the molarity of the ion present in excess after the complete reaction.

Model 1

Consider the titration of 40.0 mL of 0.200 M HBr by 0.100 M KOH, resulting in the following reaction:

$$HBr\ (aq) + KOH\ (aq) \leftrightarrow KBr\ (aq) + H_2O\ (l)$$

Calculate the pH of the resulting solution when the following volumes of KOH have been added: (a) 10.0 mL, (b) 80.0 mL, and (c) 100.0 mL.

1) In Model 1, we are adding 0.100 M KOH to 40.0 mL of 0.200 M HBr in a flask. Using the concentrations and volumes of the HBr and KOH for **part a**, calculate the moles of H^+ and moles of OH^-.

2) Looking at the balanced reaction equation in Model 1, notice that there is a 1:1 molar relationship between HBr and KOH. Therefore, one mole of HBr is needed to react with one mole of KOH. Based on this information, determine whether H^+ or OH^- is in excess and how much excess is present.

3) Using the volume from **part a**, determine the total volume in L. Then calculate the molarity of the excess ion, using the excess moles from question 2.

4) Calculate the pH of the solution at this point in the titration using the molarity from question 3.

5) Now using the concentrations and volumes of the HBr and KOH for **part b**, calculate the moles of H^+ and moles of OH^-.

6) You should notice that the number of moles in question 5 for H^+ and OH^- are equal. This means that the solution is at the equivalence point. Therefore, the pH should be 7. Confirm this statement by calculating the molarity of H^+ (divide the moles of H^+ from question 5 by the total volume of the solution for **part b** in L) and then calculate the pH.

7) Finally using the concentrations and volumes of the HBr and KOH for **part c**, calculate the moles of H^+ and moles of OH^-.

8) Determine whether H^+ or OH^- is in excess and how much excess is present.

9) Using the volume for **part c**, determine the total volume in L. Then calculate the molarity of the excess ion, using the excess moles from question 8.

10) Calculate the pH of the solution at this point in the titration using the molarity from question 9.

Below is a table that describes the necessary calculations to determine the pH at key points for a strong acid-strong base titration along the species present at each point:

Key Points	*Before Equivalence Point*	*At Equivalence Point*	*After Equivalence Point*
Calculations	Use excess $[H^+]$ ion to calculate the pH $pH < 7$	$pH = 7$	Use excess $[OH^-]$ ion to calculate the pH $pH > 7$
Species Present	H^+	H_2O	OH^-

11) Based on your calculations, which solutions (solution for part a, solution for part b, solution for c) matches the description for each key point:
   (a) Before equivalence point
   (b) At equivalence point
   (c) After equivalence point

Strong Base-Weak Acid Titration

Strong base-weak acid titrations are much more complicated to study because weak acids do not completely dissociate, making the calculations involve more steps. The key points are basically the same for this type of titration (before equivalence point, at equivalence point, and after equivalence point) but there is one point that is important: halfway to the equivalence point.

<u>Model 2</u>

A 25.0 mL sample of 0.100 M $HC_3H_5O_2$ ($K_a = 1.3 \times 10^{-5}$) is titrated with 0.100 M NaOH, resulting in the following reaction:

$$HC_3H_5O_2\ (aq) + NaOH\ (aq) \leftrightarrow NaC_3H_5O_2\ (aq) + H_2O\ (l)$$

Calculate the pH of when the following volumes of 0.100 M NaOH: (a) 8.0 mL, (b) 12.5 mL, (c) 25.0 mL, and (d) 30.0 mL.

In Model 2, 0.100 M NaOH is being added to a flask containing 25.0 mL of 0.100 M $HC_3H_5O_2$. This reaction results in a weak acid being in the presence of its conjugate base, creating a buffer solution; therefore many of the calculations will be similar to buffer solution calculations.

12) **<u>Part a</u>** involves the titration before the equivalence point. Using the concentrations and volumes, calculate the number of moles of acid and OH^- ions.

13) As this solution is a buffer solution, which part of the buffer will the OH^- ions react with: $HC_3H_5O_2$ or $C_3H_5O_2^-$?

14) Based on your answer for question 14, subtract the number of moles of OH^- ions from the moles of either the acid or conjugate base and add the number of moles to the other species.

15) Utilizing the Henderson-Hasselbalch equation below, calculate the pH for the solution for **part a**:

$$pH = pK_a + \log\left(\frac{[C_3H_5O_2^-]}{[HC_3H_5O_2]}\right)$$

16) **Part b** involves the titration halfway to the equivalence point. At this point, half of the acid titrated is neutralized; therefore, the pH is equal to the pK_a. Calculate the pH for the solution for **part b**.

17) **Part c** involves the titration at the equivalence point. The number of moles of weak acid equals the number of moles of strong base. All that is present in the solution at this point is the conjugate base ($C_3H_5O_2^-$) and calculating the pH follows the pH calculation of a basic salt.

(a) Calculate the number of moles of acid using the volume and concentration.

(b) Find the total volume of the solution for **part c**. Then assuming that the moles of the conjugate base are equal to the mole of acids calculated in part a, calculate the molarity of the conjugate base.

(c) Knowing that the salt is basic, write the equation for the reaction with it and water.

(d) Set up an ICE table and determine the $[OH^-]$. Remember you need K_b to solve for x.

(e) Using the $[OH^-]$, calculate the pH of the solution for **part c**.

18) **Part d** involves the titration after the equivalence point. The buffering capacity of the solution has been exceeded so the calculation is exactly the same as the after the equivalence point calculation for the strong acid-strong base titration. So first calculate the moles of acid and OH^- ions using the volume and concentrations of acids and base for **part d**.

19) OH^- ions should be in excess. Determine the amount of excess OH^- ions and then using the total volume of the solution in L, calculate the molarity.

20) Calculate the pH for the solution for **part d** using your answer for question 19.

The calculations for a weak base-strong acid titration are very similar to the weak acid-strong base titration with the following differences:

- The pH before the equivalence point is greater than 7.
- At the equivalence point, the pH is less than 7 since the salt formed is acidic.
- After the equivalence point, the pH is determined by the molarity of the excess H^+.

Below is a table that describes the necessary calculations to determine the pH at key points for a strong acid-strong base titration along the species present at each point:

	Key Points	*Before Equivalence Point*	*At Equivalence Point*	*After Equivalence Point*
Weak Acid-Strong Base	**Calculations**	Weak acid + conjugate base (buffer problem) pH < 7	Salt hydrolysis problem pH > 7	Use excess $[OH^-]$ ion to calculate the pH pH > 7
	Species Present	HA, A^-	A^-	OH^-
Weak Base-Strong Acid	**Calculations**	Weak base + conjugate acid (buffer problem) pH > 7	Salt hydrolysis problem pH < 7	Use excess $[H^+]$ ion to calculate the pH pH < 7
	Species Present	B, HB^+	HB^+	H^+

Characteristics of Titration Curves

It is important for you to be able to sketch and identify key points on titration curves.

Model 3

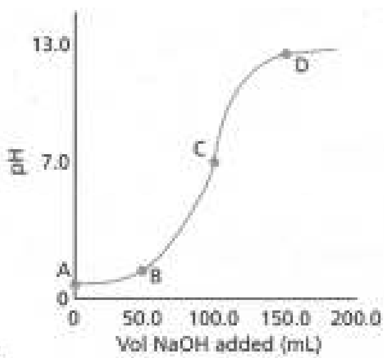

Figure 1:

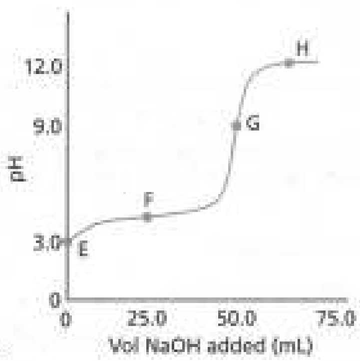

Figure 2:

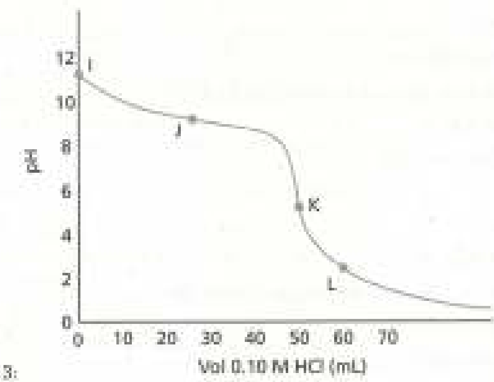

Figure 3:

21) Which titration curve in Model 3 represents:
   (a) A strong acid titrated by a strong base?
   (b) A weak acid titrated by a strong base?
   (c) A weak base titrated by a strong acid?

22) For each titration curve, label the following key points: before the equivalence point, at the equivalence point, and after the equivalence point.
23) For each lettered part of each curve (A-L), identify the major species which affect the pH. Look back the summary tables for help.

Acid-Base Indicators

The purpose of an indicator is to allow you to know when you have reached the equivalence point in a titration. Acid-base indicators are normally organic acids. Thus, when you add an indicator to a solution and perform a titration, you are titrating the indicator along with your substance of interest. This requires some small extra amount of titrant. The volume of titrant at which you visually detect the equivalence point is called the endpoint. The volume at the equivalence point is never exactly equal to the endpoint, but it is usually quite close. There are two criteria that are used to choose an indicator for a given titration:

- the pK_a of the indicator should be within ± 1 unit of the pH of the solution at the equivalence point.
- the color change at the endpoint should be clearly distinguishable.

24) Given three acid-base indicators:
    - methyl orange - endpoint at pH 4
    - bromthymol blue - endpoint at pH 7
    - phenolpthalein - endpoint at pH 9

    Select the best indicator for each of the following titrations:

    (a) sulfuric acid with potassium hydroxide
    (b) ammonia with hydrobromic acid
    (c) sodium nitrate with hydroiodic acid